Raytheon Technologies

Mission Engineering Approach for Influencing Warfighter Actions using Computational Social Sciences (IWACSS)

Paul Hershey, Ph.D.

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Problem

- As the DoD strives to incorporate advanced technologies, such as Machine Learning (ML) and Artificial Intelligence (AI), into decision support products, computer science alone is not sufficient to account for the complexity of the systems and the biases of the scientists and engineers who create them.

- Additionally, warfighters need the ability to collect, analyze, and visualize social-based-behavior data to support timely and effective decision-making for complex battle environments, such as Multi-Domain Battle Management Command and Control (MD BMC2).
- One attempt to fill this gap involves Modeling and Simulation (M&S)-based DoD military wargaming. However, previous wargaming exercises have not effectively used technology, such as AI/ML, to assist with the prediction of Red and Blue Force reaction to dynamic changes (e.g., changes in the Rules of Engagement (ROE)).
- A new Mission Engineering Approach for Influencing Warfighter Actions using Computational Social Sciences (IWACSS) is required to address these issues.

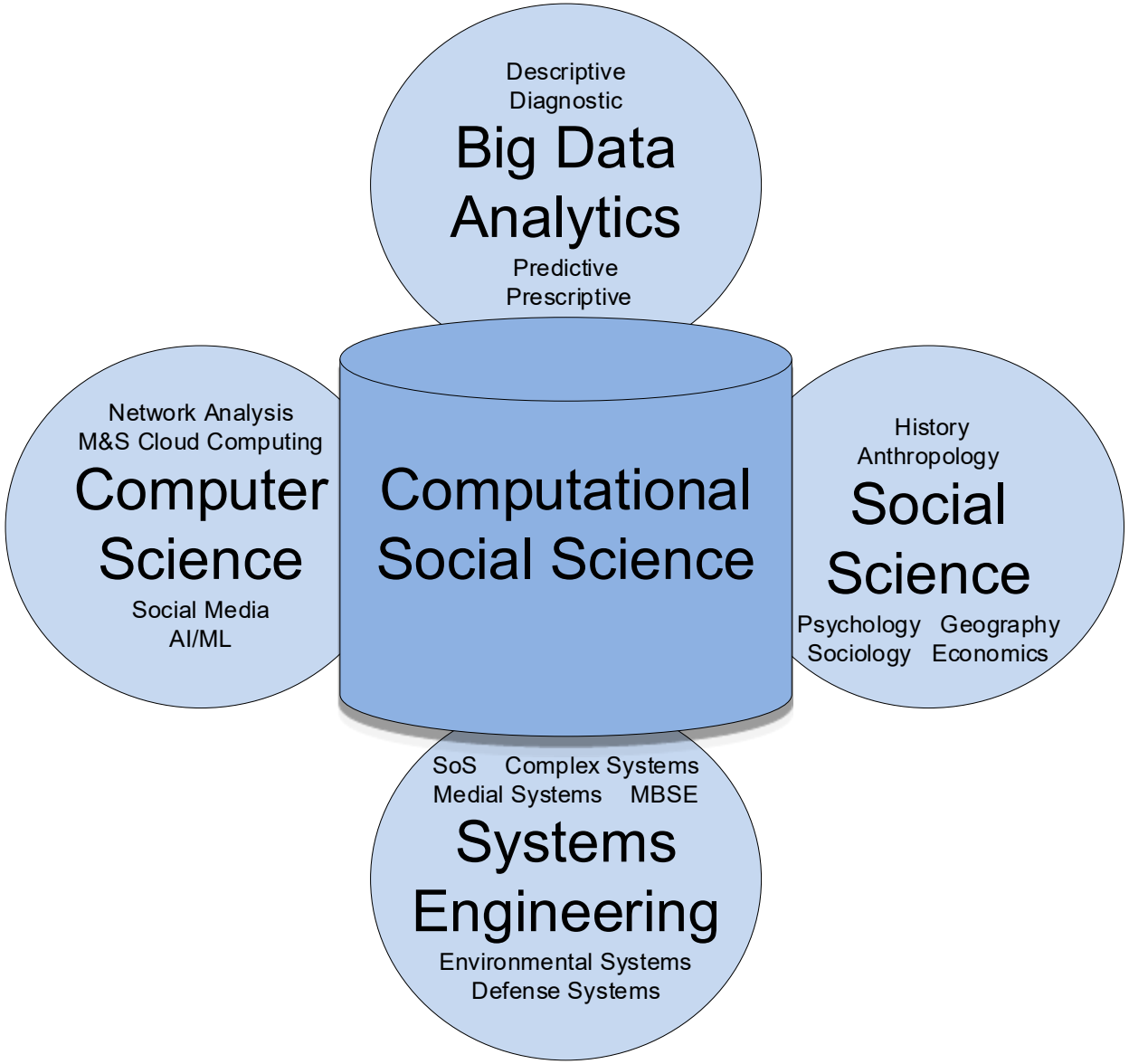
Prior Works

- Computational Social Science (CCS) has been defined as the “interdisciplinary science of complex social systems and their investigation through computational modeling and related techniques,” and may be depicted as a cross section of computer science and social science. [https://cos.gmu.edu/cds/computational-social-science/, accessed 1/30/2019].
- Other views of CSS incorporate philosophy, neuroscience, linguistics and cognitive psychology, along with Artificial Intelligence (AI) **[Cognitive Social Psychology: The Princeton Symposium on the Legacy and Future of Social Cognition 1st Edition, Kindle Edition, by Gordon B. Moskowitz (Editor) © 2001 Lawrence Erlbaum Associates, Inc.]**
- CSS investigates social complexity at all levels of analysis: cognitive, individual, group, societal, and global, through medium of computation. It is based on an information-processing paradigm of society that encompasses both pure science and policy analysis (applied science). **[https://cos.gmu.edu/cds/computational-social-science/, accessed 1/30/2019]**
- The goal of SocialSim is to develop innovative technologies for high-fidelity computational simulation of online social behavior. SocialSim will focus specifically on information spread and evolution. Current computational approaches to social and behavioral simulation are limited in this regard. **[Computational Simulation of Online Social Behavior (SocialSim) Proposers Day, DARPA-SN-17-19, January 17, 2017]**
- Causal Exploration seeks to develop a modeling platform to aid military planners in understanding and addressing underlying causal factors that drive complex conflict situations**. [Special Notice Causal Exploration of Complex Operational Environments (Causal Exploration) Proposers Day, DARPA-SN-17-11, December 02, 2016]**
- Center for Naval Analysis (CAN) designed and conducted a table-top exercise (TTX) at the U.S. Pacific Command (PACOM) Amphibious Leaders Symposium (PALS) in July 2016 that explored seabasing operations and interoperability during future contingency operations. Using a scenario that revolved around a massive natural disaster striking a fictitious country in the southern Indian Ocean, the TTX**. [Gaming Sea-based Multinational HA/DR Operations at PACOM Amphibious Leaders Symposium 2016, Catherine K. Lea, Edsel D. McGrady, Douglas J. Jackson, Daniel Powell, Elizabeth A. Collins, and Nilanthi R. Samaranayake, November 2016]**

IWACSS extends and fuses ideas in prior works by focusing CSS to influence decision making for war-fighters in the heat of battle.

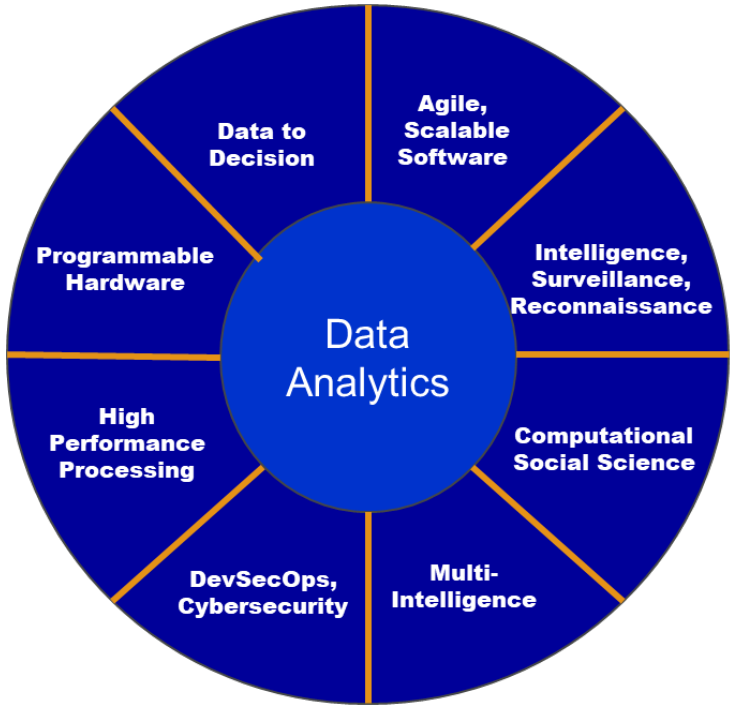
Background: CSS

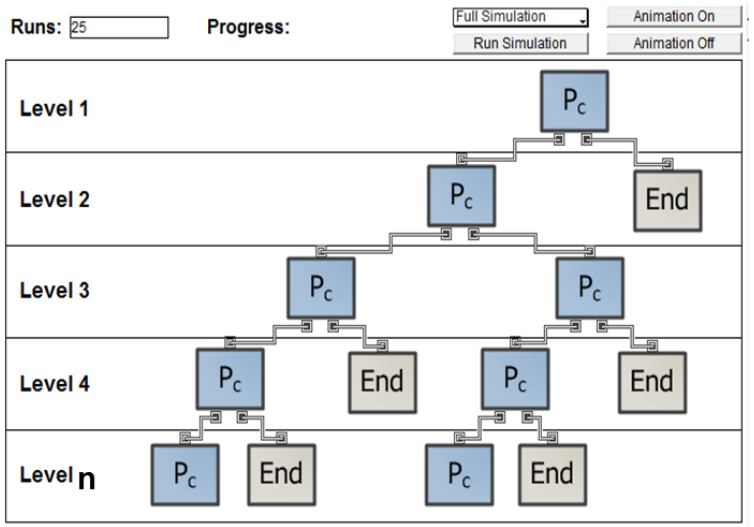
- CCS has been defined as the “interdisciplinary science of complex social systems and their investigation through computational modeling and related techniques.” [1]
- CSS may be depicted as a cross section of computer science, social science, big data analytics, and systems engineering. [2]



Background: Data Analytics

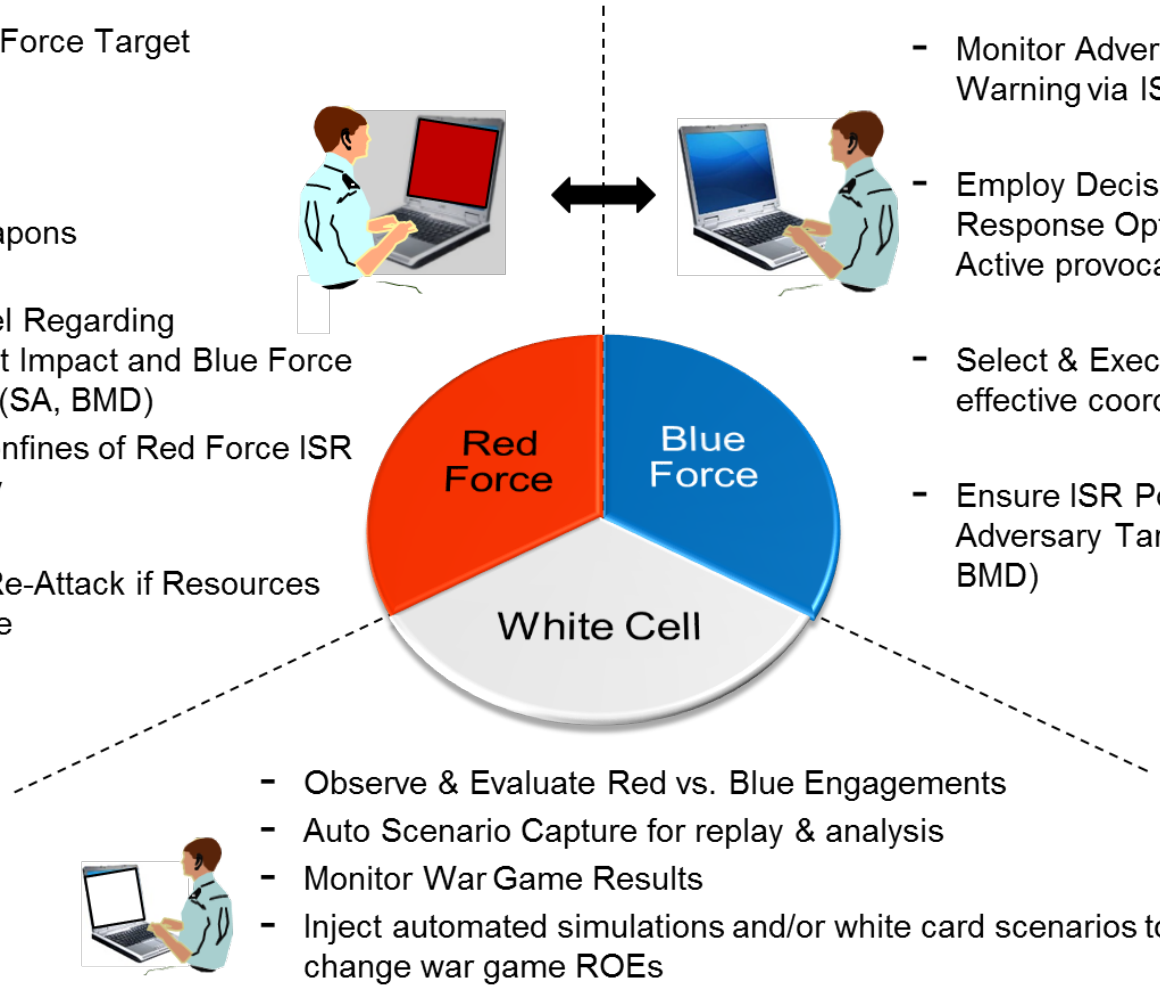
- Definition:
  - Data analytics is the science of collecting and processing raw data in order to improve human decision making
  - Data analytics encompasses many types of data and data analyses
  - Data analytics can be processed by many different hardware and software techniques
  - Data analytics supports cyber security and autonomous systems
  - Data analytics techniques can reveal trends and metrics that would otherwise be lost in the mass of raw data
- Data analytics is broken down into four basic types:
  1. Descriptive analytics describes what has happened over a given time period;
  2. Diagnostic analytics focuses on why something happened;
  3. **Predictive analytics describes what is likely going to happen in the near term;**
  4. **Prescriptive analytics suggests a course of action.**





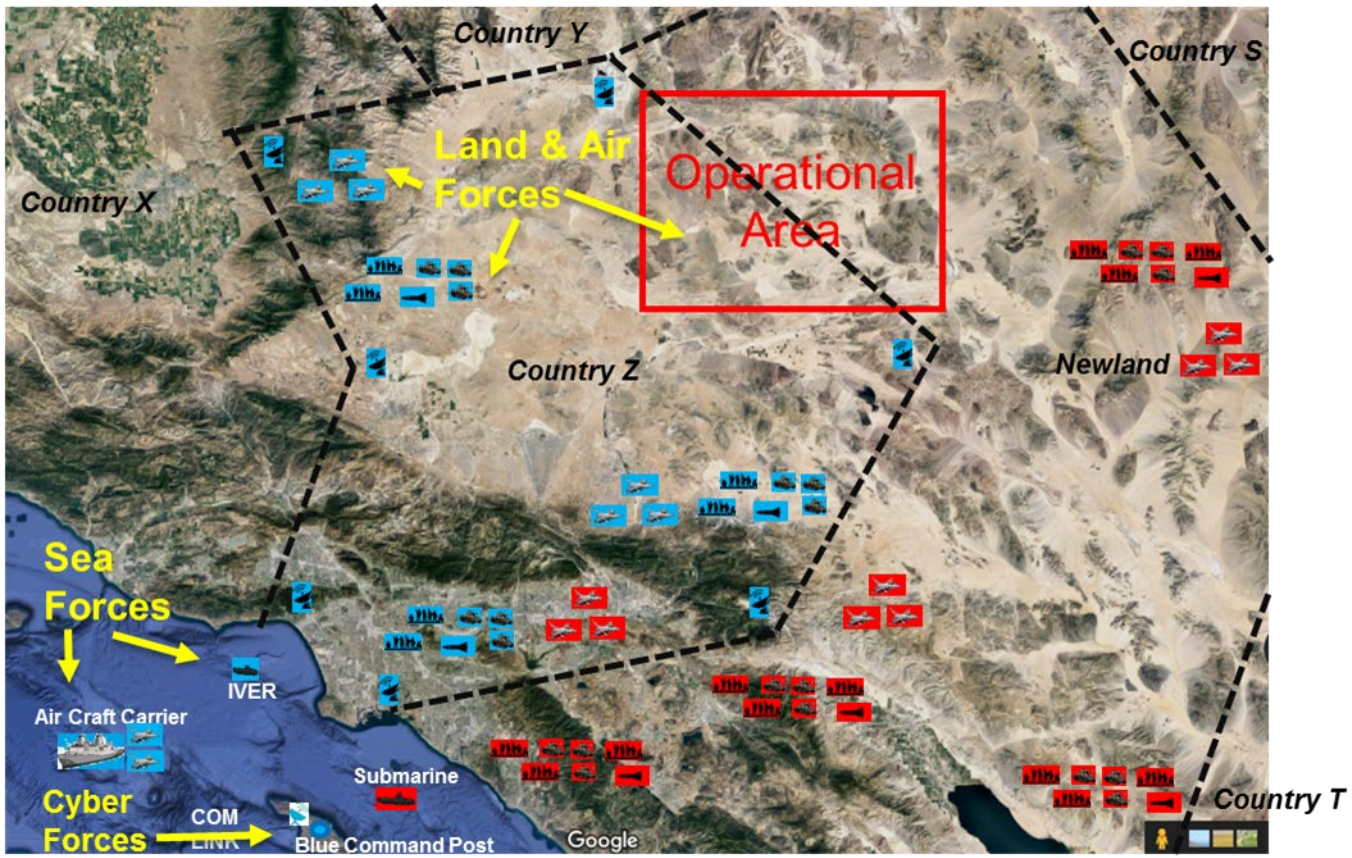
Background: Wargame

- Wargames are modeling and simulation capabilities in which theories of warfare can be explored in the absence actual warfare.
- These games assist DoD operators and analytics with tactical, operational, or strategic planning.
- There are 3 components to a wargame.
  - Blue Force (friendly)
  - Red Force (enemy)
  - White Cell (possible instructor who can observe and make changes, such as changes to the Red or Blue Force
- IWACSS includes these three elements as described in the figure.



Background: Scenario

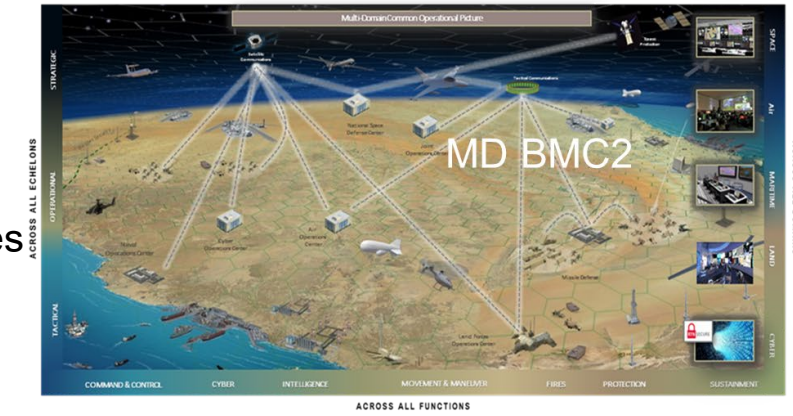
- For decades, Country Z has lived in peace with our neighbor, Newland, however, since the ascent to power 2 years ago of the son of the deceased dictator, tensions between the countries have escalated. Yesterday, during an announced military training exercise, forces from Newland the international border and are currently occupying territory within Country Z. Newland maritime forces have also been intercepted, via SIGINT, of planning coastal operations against undefended ports of entry. Additionally, Newland UAVs have been seen, via SIGINT, operating in the Northeastern sector.
- Blue forces from Country Z are tasked to repel the invaders from our territory, pushing them back at least 50 kilometers from our border in the area of conflict. In addition, our border defenses must be shored up over all domains, to prevent another incursion into our territory. Denying the enemy intel on our movement is key to our success so eliminating this ISR source and denying access to Red satellites is critical. Protecting our borders, our military C2 headquarters, and our capital city are essential. To prevent re-attack, we must soften the enemy border defenses, with a longer-term goal of taking out Newland defenses along the Country Z border. Make every effort to avoid civilian casualties, and provide protection to our citizens in the area of conflict. Evacuation has been ordered from the area of conflict, but some patriotic citizens remain in place to fight against the invaders. Reserve forces are located on an island outside of the area of operations.

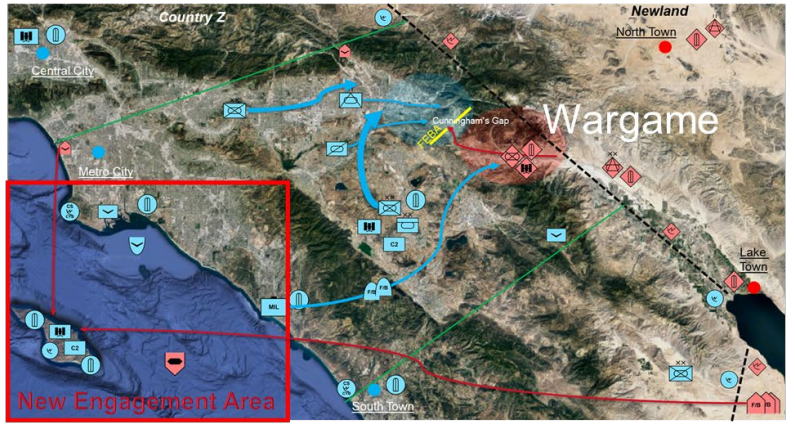


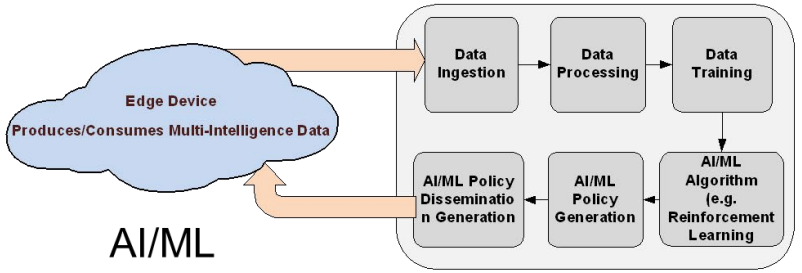
Approach

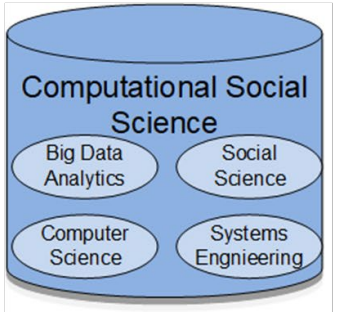
The IWCSS method enables the end-users to accomplish the following complex mission engineering functions:

1. Combine war-gaming techniques with CSS through a white cell dynamically changing rules of engagement for Red Force and Blue Force
2. Demonstrate ability of white cell to apply “Deception” to change the Rules of Engagement (ROE) and, thereby, influence multiple mission functions, including: Course of Action (COA) Generation, COA Analysis, Mission Feasibility Analysis
3. Demonstrate ability of red and blues forces to respond to ROE at speed of battle: Self-healing COA
4. Introduce gamification concepts to support intuitive and time-efficient use by end-users







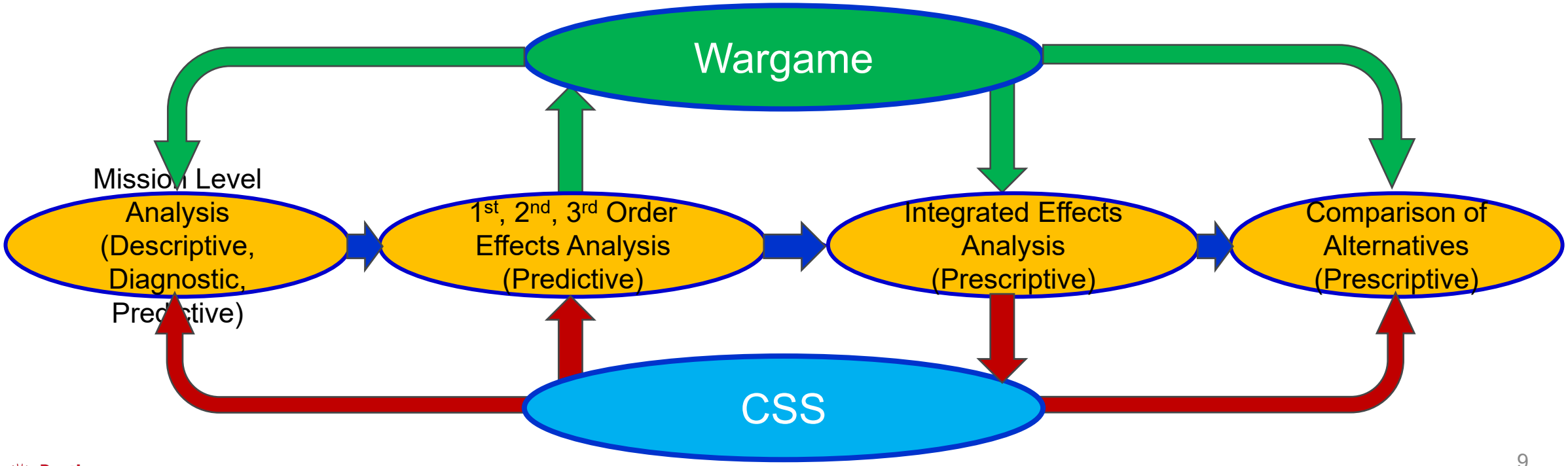


Computational Social Science (CSS)

5. Apply **Artificial Intelligence and Machine Learning** to actual and synthetic data training sets to enable white cell to determine expected behavior of red and blue forces in the face of mission events. Include use of predictive analytics
6. Demonstrate new **M&S, AI, and ML IWACSS method for multi-domain battle management command and control scenarios** of interest military supported and supporting commands. These scenarios would include both Unclassified and Classified cases, where classification is determined based on classification of training data
7. Analyze **integrated kinetic and non-kinetic fires** across all mission phases
8. Evolve to real-time decision support, and incorporate emerging, high speed effects such as hypersonic weapons
9. Extend to Asymmetrical Warfare analysis and assessment

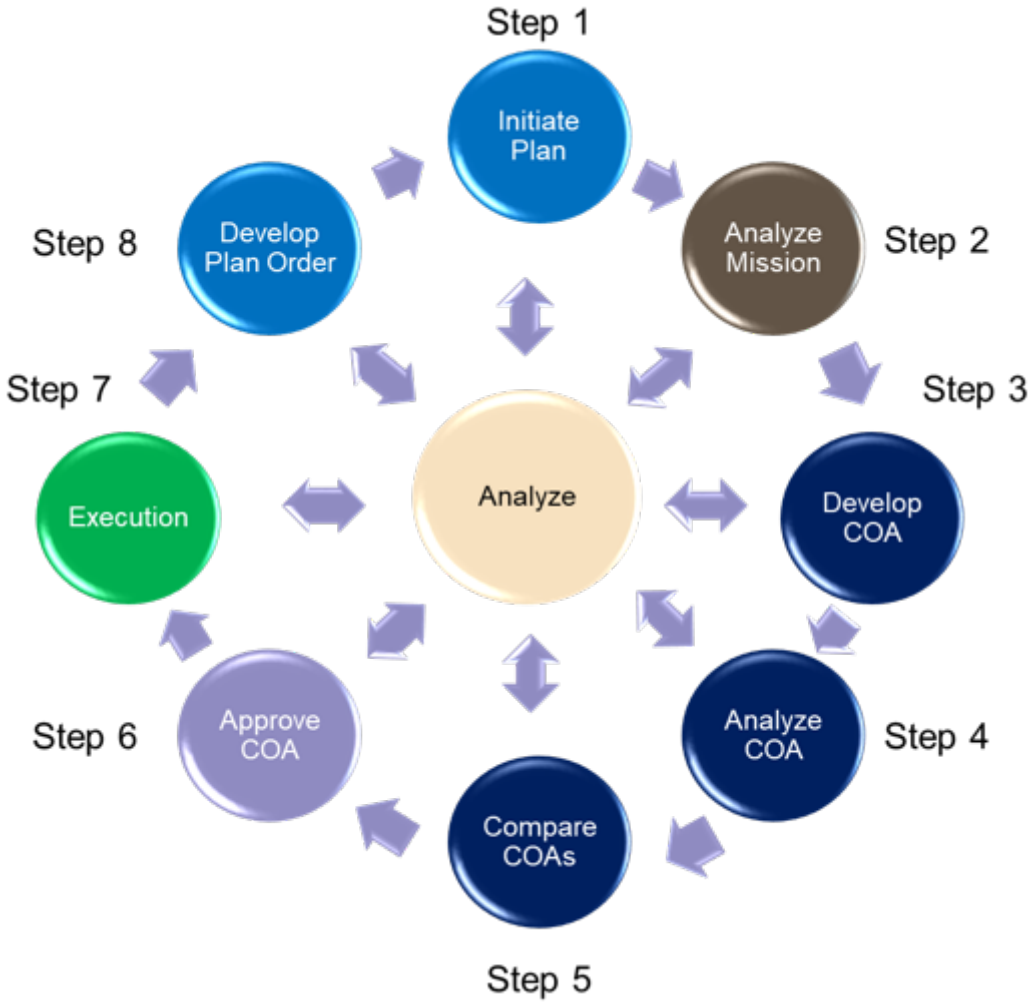
Approach: Relationship between CSS and Wargame

- Combine detailed COA development , analysis, and comparison, from wargame with CSS engine
  - Wargame produces results for initial performance measures through RL and predictive analytics
  - CSS engine checks for 1st, 2nd, and 3rd order effects and provides feedback to wargame to refine performance analysis (predictive analytics).
  - After sufficient iterations, the confidence level in performance analysis reaches the desired threshold and calculates effect and wargame outcome results for alternative COAs (prescriptive).
  - Alternative COA results are compared and best COA to meet commander's intend is selected



Approach: Dynamic COA Update - SCOAR

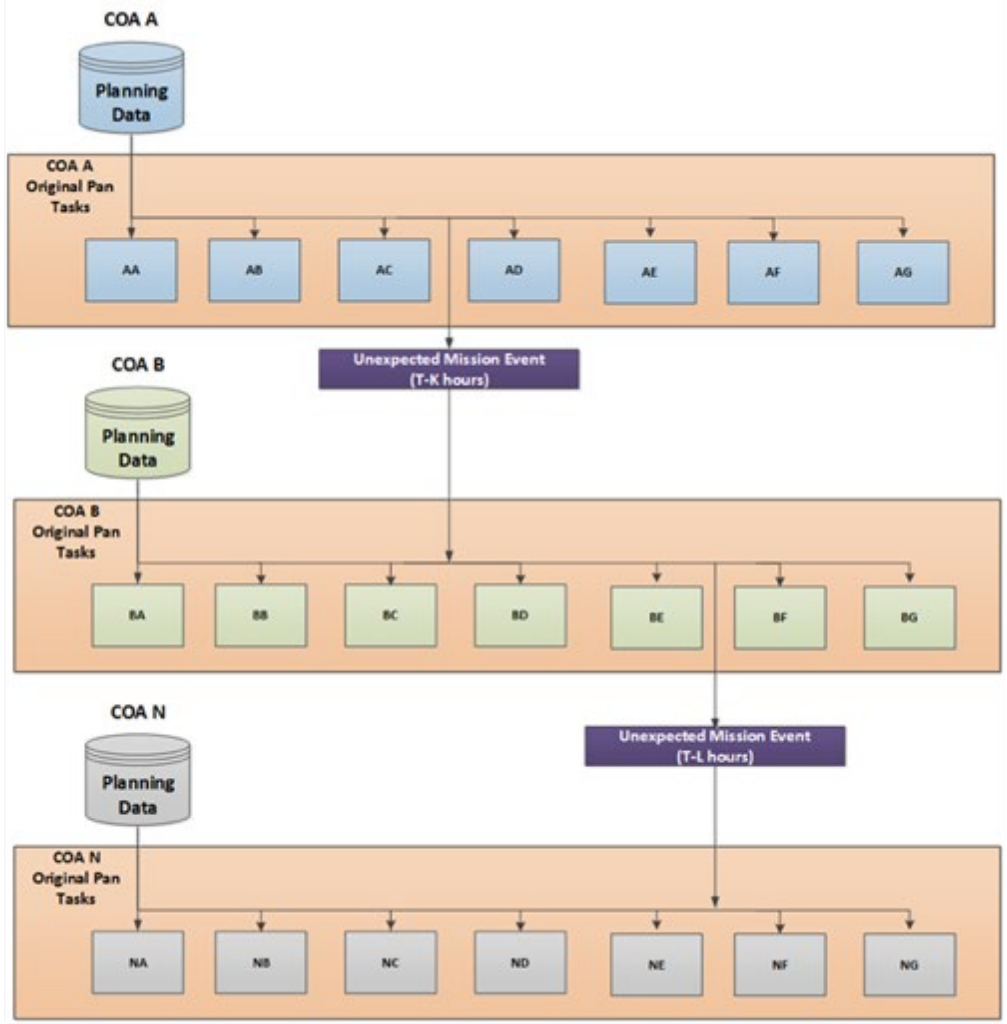
- The COA process requires 7 steps for COA revision:
  - Initiate plan, analyze mission, COA generation (including COA development, COA analysis, and COA comparison), COA approval, and develop COA plan order
- After the mission initiation, there is no opportunity for COA adjustment if events change unexpectedly
  - Changes in the Rules of Engagement (RoE)
- A new Self-Healing Course of Action Revision (SCOAR) technique based on Reinforcement Learning (RL) was applied to vented to enable dynamic adjustments in the COA
  - Continuously assesses mission events during mission execution
  - Applies machine learning to adjust the presently executing COA dynamically.
    - Asset positions, maintenance, and tasking - actively monitored
    - If the primary asset suffered attrition or was unable to complete its goals, then next best asset automatically tries to take its place
    - If no assets are available, swaps out the COA activity being performed for an activity in a different COA that achieves the same end state



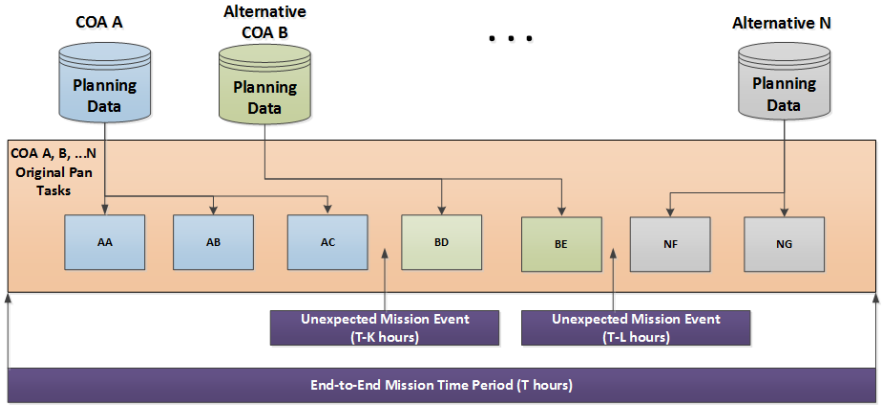
COA Revision Process

Approach: Example

- In this example, “N” different COAs are planned and generated for a defined mission in a **wargame**.
- During COA compare, COA A is selected as the COA to execute during the mission.
- However, after the mission is initiated and has begun executing, unexpected mission events occurred (**such as 1st , 2nd or 3rd order events injected by white cell**) at mission times T-K hours and T-L hours, where T hours is the total mission time and K hours and L hours are times less than T hours.
- SCOAR enables the overall mission COA to move from COA A activities to COA B activities and eventually to COA N activities as mission events change.
- This COA revision and assessment process is done without repeating the entire COA generation process.



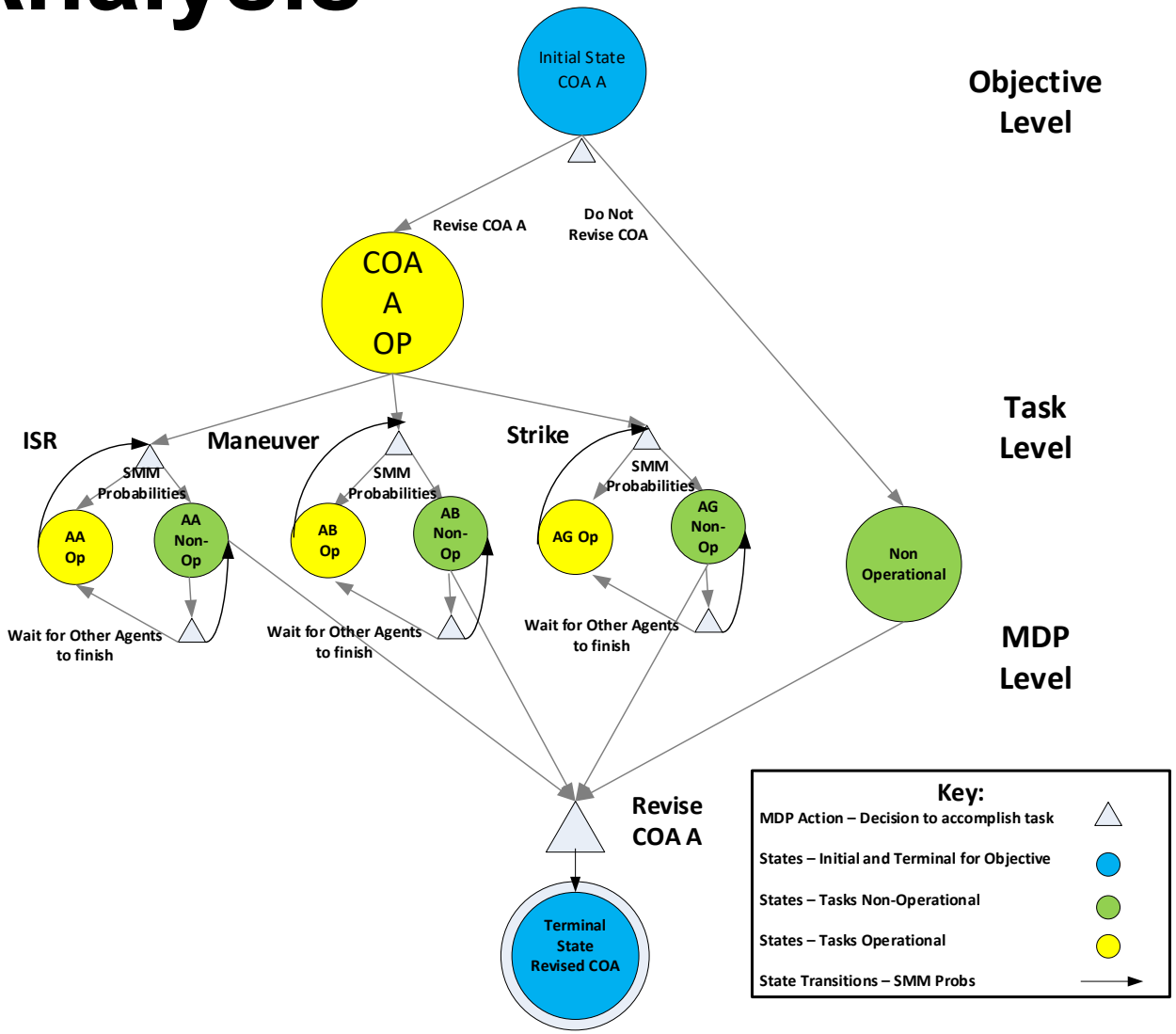
Individual COA Response to Unexpected Mission Events



Combined COA Response to Unexpected Mission Events

Approach: Predictive Analysis

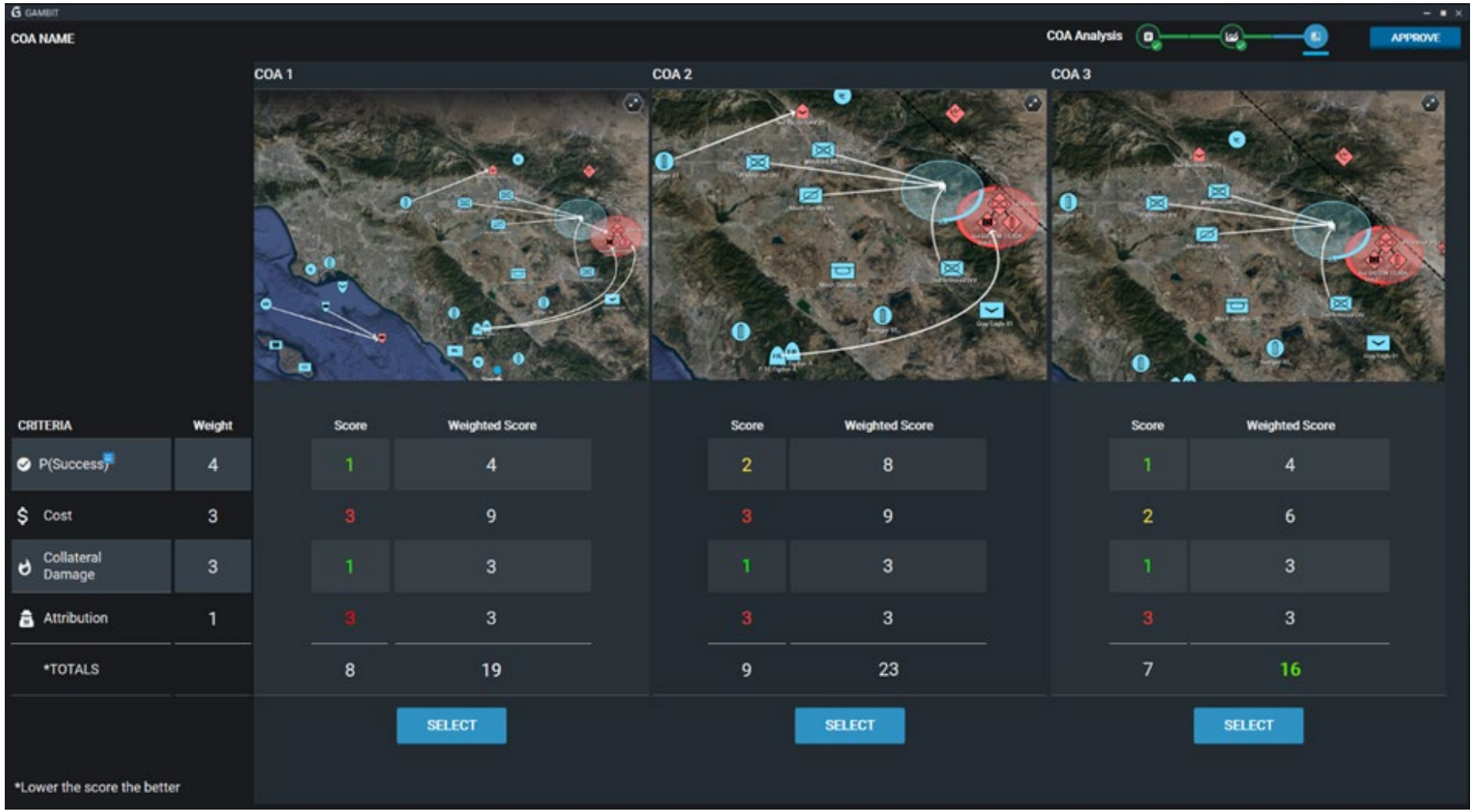
- Analysis approach applies Markov Decision Processes (MDP) and Stochastic Mathematical Model (SMM)
- Represents all COA activities for mission as a non-deterministic state machine in which each activity is a state
- Applies Markov Decision Processes (MDP) to determine all possible state transitions
- Computes transition probabilities (Psuccess) and associated confidence intervals (CI) between all COA activities using the SMM.
- Uses a new method to Propagate Transition Probabilities (Psuccess) and associated Confidence Intervals (CI) across COA Activities.



SCOAR Notional MDP Representation of a COA Task

Results: IWACSS Prototype –Prescriptive Analytics

- Implemented a prototype that generated metrics relevant commander's criteria for three alternative COAs.
  - Compared each COA with respect those metrics
  - COAs 2 and 3 were revised as Rules of engagement (RoE) changed during the simulated battle.
  - Each COA was given a weighted score to help both the mission planner and the commander determine whether the revised COA resulted in a better plan.
    - In accordance with military doctrine, lower score wins
    - COA 3 provided lowest score for metrics considered



COA Results and Comparison

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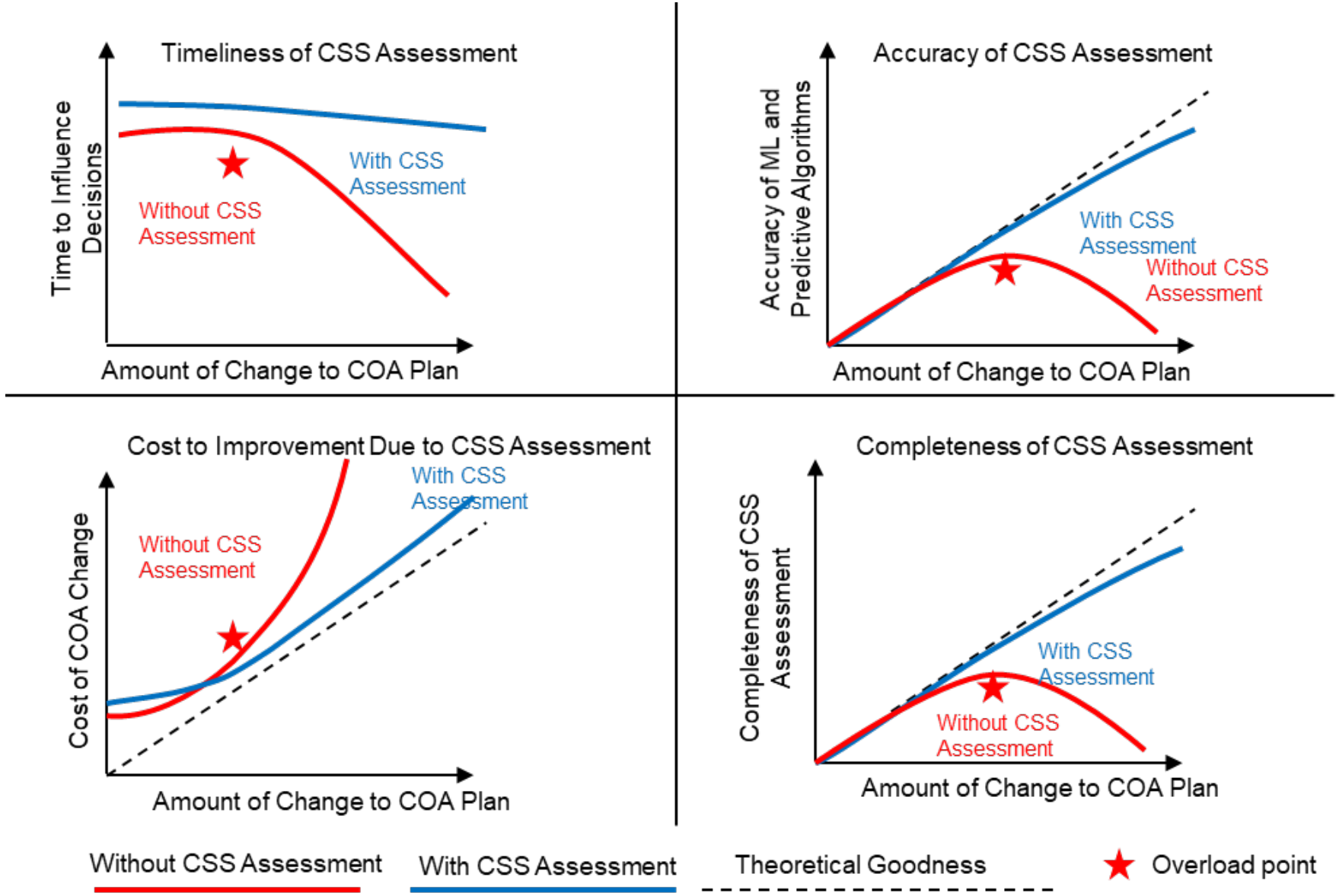
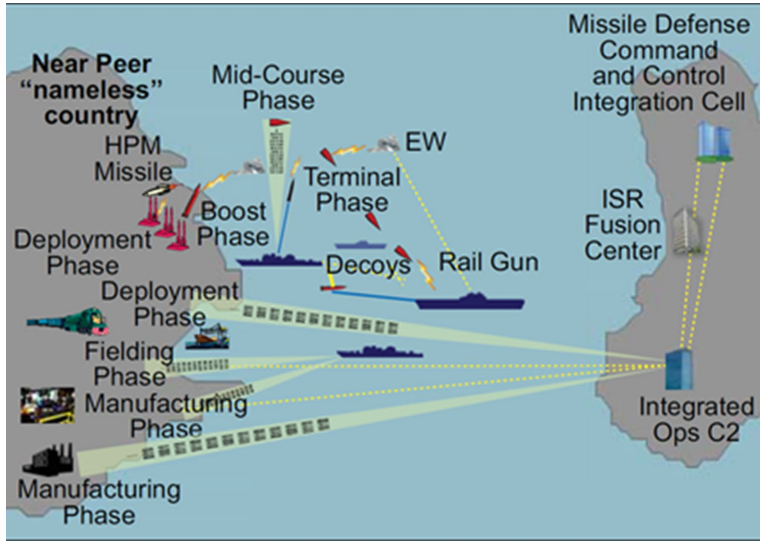
Notional Results – Improvement to Wargame Results with CSS

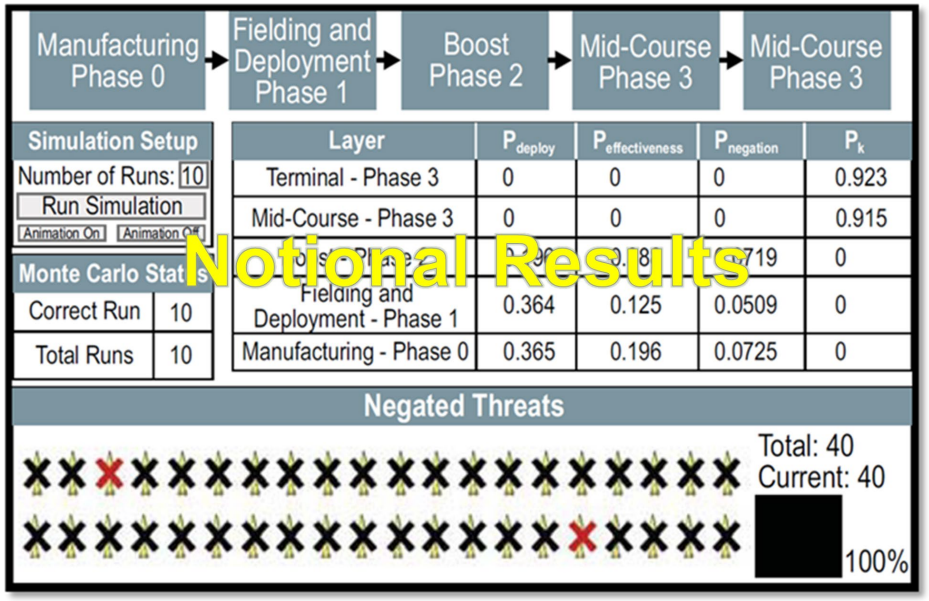


Notional Results for Integrated Kinetic/Non-kinetic Fires

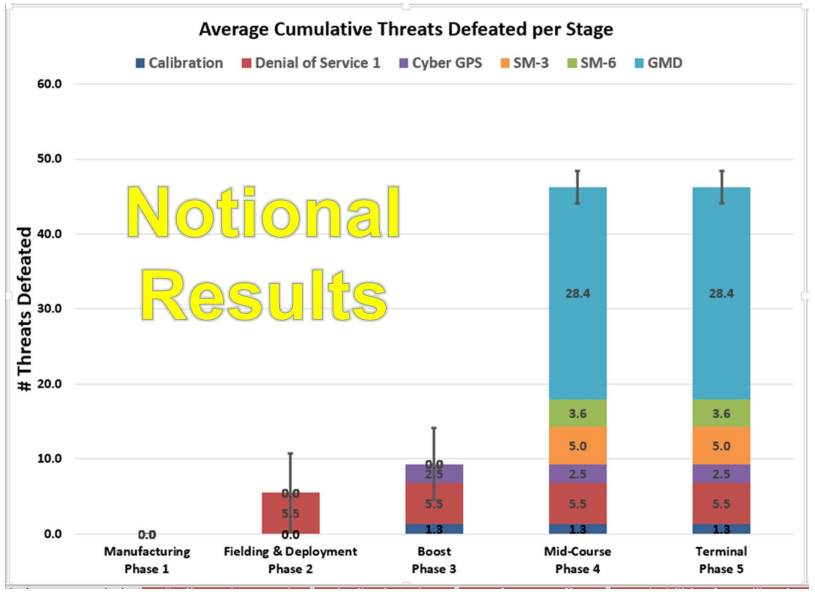
- IWACSS applied SMM and SCOAR to derive results for a notional multi-domain Integrated Air and Missile Defense (IAMD) Scenario.



- SCOAR used prescriptive analytics to permit consideration of alternative 1st, 2nd, and 3rd order effects per mission phase



- SMM derived predictive analytics results for Probability of Defeat for individual and integrated kinetic and non-kinetic threat/effect pairings per mission phase.



Conclusion

- Presented an approach that integrates wargaming and Computation Social Science such that red-force and blue force square off to fight, while a white cell player applies deception to manipulate red force blue force Courses of Action (CoAs).
- White Cell has the ability to inject unexpected events that can change the Rules of Engagement (ROE) between Red Force and Blue Force.
- Introduces a new Self-Healing Course of Action Revision (SCOAR) capability that enables dynamic adjustments in the COA
- Events are meant to elicit responses due to both subjective social interpretation and objective rules-based interpretation.
- CSS will also be used to assist red and blue force teams in predicting the next move of the other.

Backup

Abstract

As the DoD strives to incorporate advanced technologies, such as Machine Learning (ML) and Artificial Intelligence (AI), into decision support products, computer science alone is not sufficient to account for the complexity of the systems and the biases of the scientists and engineers who create them. Additionally, warfighters need the ability to collect, analyze, and visualize social-based-behavior data to support timely and effective decision-making for complex battle environments, such as Multi-Domain Battle Management Command and Control (MD BMC2). One attempt to fill this gap involves Modeling and Simulation (M&S)-based DoD military wargaming. However, wargaming exercises do not effectively use technology, such as AI/ML, to assist with the prediction of Red and Blue Force reaction to dynamic changes, such as changes in the Rules of Engagement (ROE). A new mission engineering approach is required to address these issues.

In this paper, we present such a mission engineering method and system for Influencing Warfighter Actions using Computational Social Sciences (IWACSS) to fill the gap in both in traditional DoD wargaming and in emerging Computational Social Science. IWACSS incorporates the social domain into battle management where real-time analysis is required to support timely decision-making. Our extensive research of prior literature and patents reveals that, although prior wargaming has incorporated aspects of social science, these attempts fail to provide calculated results derived from mathematically-based prediction that consider the effects (e.g., 1st, 2nd, and 3rd order effects) of social parameters on the outcome of the battle. In fact, for these approaches, the concept of applying predictive techniques is limited based on the perceived randomness of human social behavior. IWACSS overcomes this limitation by applying foundational stochastic mathematics and CSS techniques in combination with Reinforcement Learning (RL) to improve timely decision making and provide predictive results that include confidence levels.

The IWCSS method enables the end-users to accomplish the following complex mission engineering functions:

- Apply war-gaming techniques with white cell dynamically changing rules of engagement for Red Force and Blue Force
- Demonstrate ability of white cell to apply “Deception” to change the Rules of Engagement (ROE) and, thereby, influence multiple mission functions, including: Course of Action (COA) Generation, COA Analysis, Mission Feasibility Analysis
- Demonstrate ability of red and blues forces to respond to ROE at speed of battle: Self-healing COA
- Introduce gamification concepts to support intuitive and time-efficient use by end-users
- **Apply Artificial Intelligence and Machine Learning** to actual and synthetic data training sets to enable white cell to determine expected behavior of red and blue forces in the face of mission events. Include use of predictive analytics
- Demonstrate new **M&S, AI, and ML IWACSS** method for multi-domain battle management command and control scenarios of interest military supported and supporting commands. These scenarios would include both Unclassified and Classified cases, where classification is determined based on classification of training data
- Analyze **integrated kinetic and non-kinetic fires** across all mission phases
- Evolve to real-time decision support, and incorporate emerging, high speed effects such as **hypersonic weapons**
- Extend **to Asymmetrical Warfare** analysis and assessment

Preliminary results were generated using the IWACSS prototype for three alternative COAs. These results were compared with respect to how they met the Commander’s criteria for selected metrics including Probability of Mission Success (Psuccess) with associated Confidence interval, Cost, Collateral Damage, and Attribution. **RL was used to enable dynamic adjustment of COAs** in response to changes in the RoE during the simulated battle. The results were presented to the end-users in the form of a decision matrix in which each COA was given a weighted score to help the mission planner and the commander determine whether the revised COA resulted in a better plan.

Bio

Paul Hershey works for Raytheon Technologies Company, where he is a Principal Engineering Fellow focusing on data analytics, autonomous systems, modeling and simulation, and cyber security. He has been a member of IEEE since 1980 and was elevated to IEEE Fellow in 2021. He received his Ph.D. and M.S. degrees in electrical engineering from the University of Maryland, College Park, MD, USA, and the A.B. degree in mathematics from the College of William and Mary, Williamsburg, VA, USA. Dr. Hershey has published 39 patents (granted) and over 60 peer-reviewed technical articles. Previously, he was an adjunct professor at George Washington University where he also served on the Curriculum Advisory Board. He presently serves on technical program committees for the IEEE International Systems Conference and the IEEE International System of Systems Engineering Conference. Dr. Hershey is a Distinguished Lecturer on data analytics for the IEEE Systems Council.